

NiCrBSi coating obtained by laser cladding and subsequent deformation processing

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Abstract. NiCrBSi coating (Ni: base; Cr: 18.2 wt%; B: 3.3 wt%; Si: 4.2 wt%; C: 0.92 wt%; Fe: 2.6 wt%) formed by gas powder laser cladding is subjected to subsequent deformation processing, namely, frictional treatment with a sliding indenter made of dense cubic boron nitride in air under loads of 300 to 700 N, with 2 to 5 scans of the surface. This treatment strengthens the surface and forms favorable residual compressive stress, whose level increases with the load on the indenter. Frictional treatment under loads of 500 N and higher causes intensive strain-induced dissolution of Ni₃B borides and Cr₇C₃ carbides in a Ni-based γ -solid solution.

1. Introduction

In modern engineering production the most important task is to increase the service life of parts and assemblies manufactured friction and introduced earlier in the operation of vehicles [1]. Laser cladding is an advanced technology to restore the work dimensions of machine parts and extend the serviceability of machines. Self-fluxing NiCrBSi alloy powders characterized by high wear resistance [2–6] are finding a wide application as materials for this purpose.

Significant surface undulation and roughness is a characteristic feature of clad layers [7]. This is inadmissible for precision friction units. Conventional grinding of clad surfaces by abrasive wheels may be accompanied by the appearance of “burns” and microcracks, as well as dangerous tensile stresses.

The surface plastic deformation is an efficient way to increase the strength and wear resistance of machine part surfaces. Prospects of the application of frictional treatment as finishing surface deformation processing of NiCrBSi coatings was demonstrated in [8] for the relatively plastic laser clad coating PG-SR2, with average microhardness 570 HV 0.025 and the hardness of the strengthening phases not exceeding 1000–1050 HV (Ni: base; Cr: 14.8 wt%; B: 2.1 wt%; Si: 2.9 wt%; C: 0.48 wt%; Fe: 2.6 wt%).

However, frictional treatment is also applicable to much more high-strength and hard-to-deform metal materials [9, 10]. The aim of this work is to study whether the use of frictional treatment can improve the characteristics of the surface layers of the NiCrBSi—PG-10N-01 high-strength coating containing higher amounts of carbon, chromium, boron and silicon than the PG-SR2 clad coating.



2. Experimental

A plate of low-carbon (0.20% C) steel was clad with a powder of grade PG-10N-01 (Ni: base; Cr: 18.2 wt%; B: 3.3 wt%; Si: 4.2 wt%; C: 0.92 wt%; Fe: 2.6 wt%) by continuous CO₂ laser. Cladding was performed in two passes with a radiation power of 1.4–1.6 kW, a speed of 160 mm/min, powder consumption of 2.9 to 3.8 g/min and a laser spot of 61.5 mm on the surface. The clad surfaces were ground on a circular grinding machine with intensive cooling. Figure 1 shows a cross-section of a coated specimen after grinding.

Frictional treatment of flat clad specimens, ground and mechanically polished, was performed by a reciprocal sliding of a hemispherical indenter made of dense cubic boron nitride (DBN) with a radius $r = 3$ mm (figure 2) under loads ranging from 300 to 700 N in air, with an average speed of 0.013 m/s, a stroke length of 18 mm, double stroke displacement of 0.1 mm, 2–5-fold scanning. The treatment offered the absence of any appreciable frictional heating of the friction surface.

The coating surfaces were studied by using a VEGA II XMU scanning electron microscope. The surface roughness was examined on a Wyko NT-1100 optical profilometer. Microhardness was determined on a Shimadzu HMV-G21DT microhardness meter by the restored print method. Residual stresses in the surface layer of the coating were estimated by tilted photography along the (220) line of the Ni-based γ -solid solution on a Shimadzu XRD-7000 x-ray diffractometer. The phase composition of the coatings was studied with the use of a Shimadzu XRD-7000 x-ray diffractometer and a VEGA II XMU scanning electron microscope equipped with an INCA Wave 700 wavelength dispersive microanalyzer and an INCA Energy 450 XT energy dispersive microanalyzer.

3. Results and discussion

The process parameters of the frictional treatment of the surface with sliding indenters are optimized by the criteria of effective hardening and a high quality of the treated surface (low roughness, the absence of seizure and microcracking).

It follows from the data shown in table 1 that frictional treatment by a sliding DBN-indenter in air under all the used loads ($P = 300$ –700 N) increases coating surface hardening (to 1165–1220 HV 0.025) as compared to the microhardness of the ground (1045 HV 0.025) and polished (990 HV 0.025) states. Besides, the ground coating is characterized by the presence of dangerous tensile stresses on the surface, whereas the frictional treatment of the coating causes favorable compressive stresses (see table 1). As the load on the indenter increases, microhardness grows to 1220 HV 0.025 and the level of residual compressive stresses grow to -1140 MPa under the loads $P = 700$ N. A more effective hardening and a higher level of compressive residual stresses under maximum loads ($P = 700$ N) are attained even with a smaller number ($n = 2$ –4) of indenter passes (scans) than under the loads $P = 300$ –500 N ($n = 5$).

According to figure 3, the frictional treatment of the PG-10N-01 coating forms higher quality surfaces than grinding does. It has been experimentally established that treatment under the loads $P = 300$ –500 N ensures the absence of seizure on the coating surface with five scans ($n = 5$) of the surface by an indenter. The number of scans without seizure is $n = 4$ for the load $P = 700$ N. Therewith, in all the studied cases, the value of the arithmetic mean deviation of the roughness profile does not exceed the value $Ra = 0.2$ μm . Figure 3(a) shows that, during surface preparation by machine grinding, the mechanism of abrasive wear with a large share of micromachining is implemented. After frictional treatment there are smoothed surfaces typical of the fatigue mechanism of wear, see figure 3(b, c). Under the load $P = 700$ N, on the friction surface there appear separate microcracks perpendicular to the direction of the indenter motion, marked by arrows in figure 3(c). These cracks result from low-cycle friction fatigue [11].

The phase composition of the PG-10N-01 coating in the initial clad state is as follows: a Ni-based γ -solid solution, eutectics γ +Ni₃B, the hardest strengthening phases Cr₇C₃ and CrB,



Figure 1. A cross-section photograph of a coated specimen after cladding and grinding.

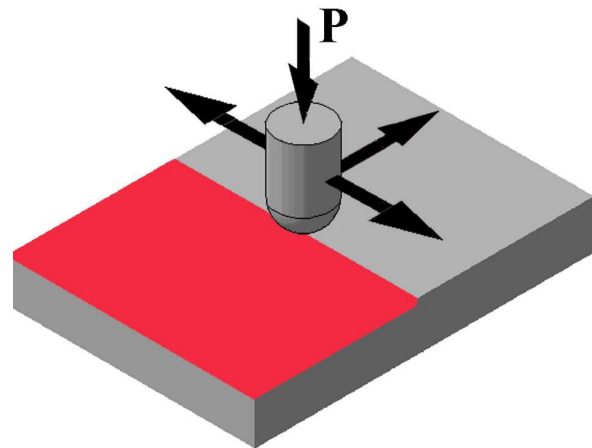


Figure 2. Scheme of frictional treatment with a hemispherical indenter.

Table 1. Microhardness HV 0.025, residual stresses σ and the average values of the lattice parameters of the γ -solid solution d on the PG-10N-01 coating surface after grinding, polishing and frictional treatment with a DBN-indenter in air under a load P and the number of passes n .

Treatment	P (N)	n	HV 0.025	σ (MPa)	d (Å)
Grinding	—	—	1045 ± 30	+90	—
Polishing	—	—	990 ± 35	−85	3.5394
Frictional treatment	300	5	1170 ± 70	−55	3.5374
	500	5	1210 ± 20	−135	3.5418
	700	2	1165 ± 30	−590	3.5422
	700	4	1220 ± 35	−1140	3.5424

figure 4(a) [8]. The frictional treatment of the PG-10N-01 coating by a DBN-indenter under the minimum load ($P = 300$ N) does not lead to a qualitative change in the phase composition of the coating—only a decrease in the intensity of the lines of the strengthening phases is observed in the x-ray diffraction pattern, figure 4(b). This may testify to their partial strain-induced dissolution.

In the process of frictional treatment under the loads $P \geq 500$ N, practically complete strain-induced dissolution of nickel borides Ni_3B and chromium carbides Cr_7C_3 occurs in the thin surface layer. The phase composition on the coating surface after the treatment is as follows: Ni-based γ -solid solution and the retained hardest strengthening phase CrB (up to 2420 HV 0.025), see figure 4(c). The dissolution of the strengthening phases during frictional treatment with the loads $P = 500$ –700 N and the number of indenter passes (scans) $n = 2$ –4

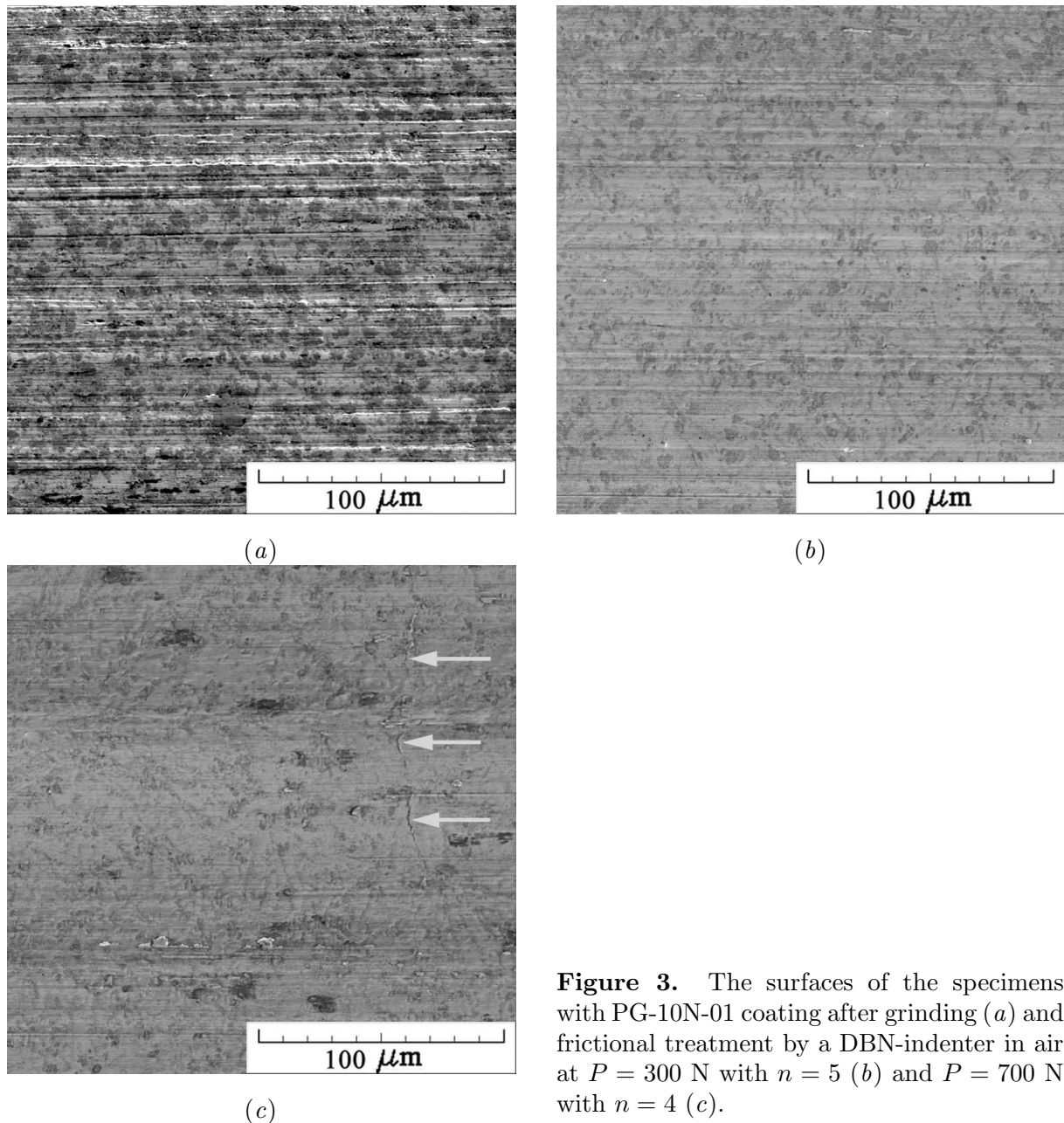


Figure 3. The surfaces of the specimens with PG-10N-01 coating after grinding (a) and frictional treatment by a DBN-indenter in air at $P = 300$ N with $n = 5$ (b) and $P = 700$ N with $n = 4$ (c).

increases the γ -lattice parameter (see table 1) due to the enrichment of the Ni-based γ -solid solution with carbon, chromium and boron. The observed intensive strain-induced dissolution of the phases is favored by the development of rotational plasticity in the surface layer during frictional treatment leading to the formation of the nanocrystalline state [12] and by a high degree of accumulated plastic strain [13].

The obtained results testify to a more efficient accumulation of plastic strain in the surface layer of the coating during frictional treatment when the load on the indenter grows from $P = 300$ to 500–700 N. This manifests itself in the change of the phase composition of the coating, see figure 4(c), and in the increased lattice parameter of the Ni-based γ -solid solution after frictional treatment under the loads $P = 500$ –700 N with the number of scans $n = 2$ –5. However, in the case of frictional treatment with a minimum load on the indenter ($P = 300$ N) the deformation

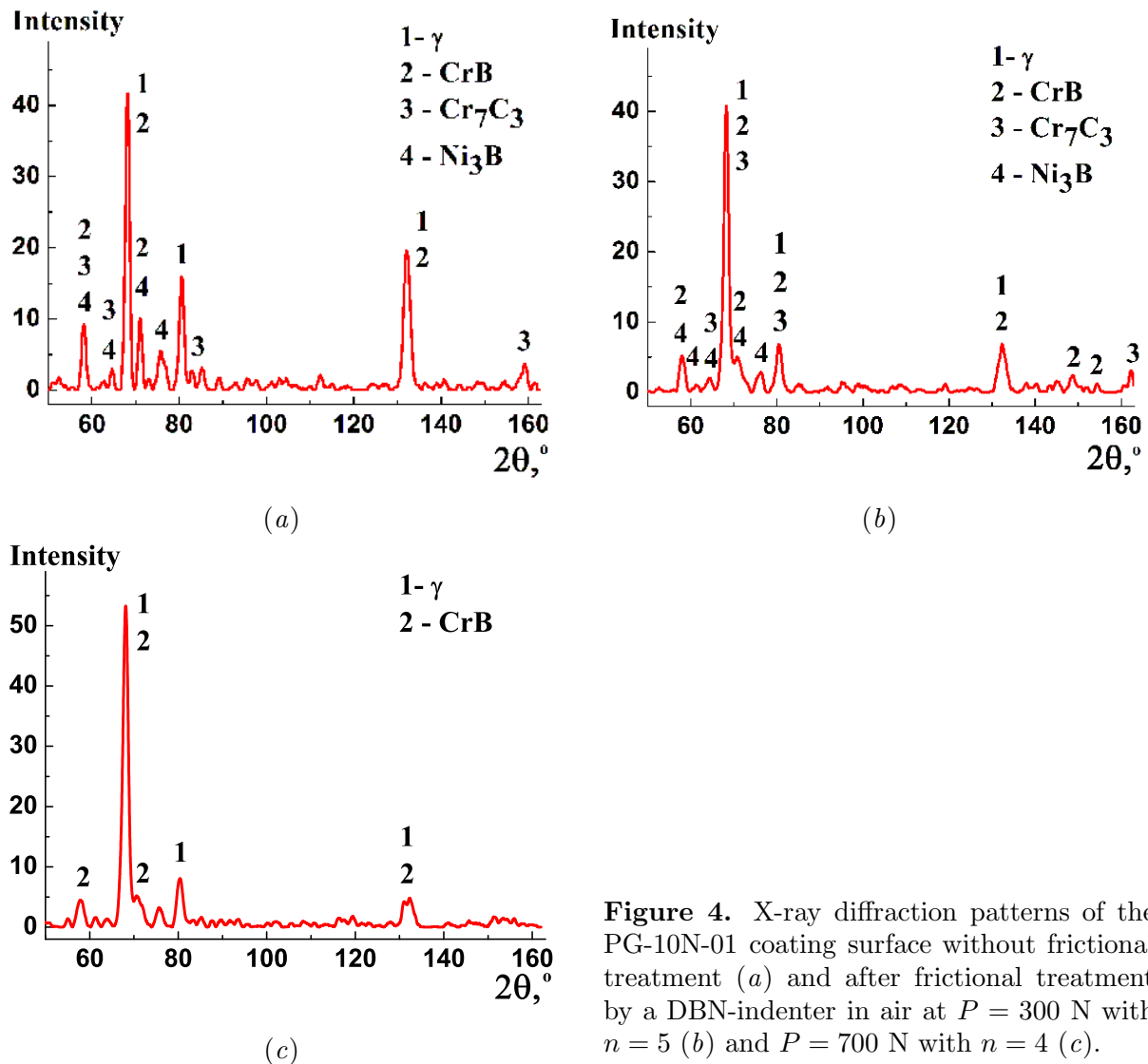


Figure 4. X-ray diffraction patterns of the PG-10N-01 coating surface without frictional treatment (a) and after frictional treatment by a DBN-indenter in air at $P = 300$ N with $n = 5$ (b) and $P = 700$ N with $n = 4$ (c).

processes are less developed even with five scans. This results in a less intensive strain-induced dissolution of nitrides and carbides, see figure 4(b), and in the absence of any increase in the γ -lattice parameter (see table 1).

The high level of microhardness (1165–1220 HV 0.025) on the coating surface after frictional treatment shown in table 1 is attributed to the effect of the following strengthening mechanisms:

- (1) solid solution strengthening—due to the saturation of the Ni-based γ -solid solution with carbon, chromium and boron, with partial or complete strain-induced dissolution of nitrides and carbides;
- (2) dislocation and grain-boundary hardening—due to the formation of a fine-grained structure in the surface layer, with a high dislocation density and developed grain and subgrain boundaries, this being typical of the frictional treatment of high-strength alloys [10, 12];
- (3) dispersion hardening—due to the presence of dispersed and incompletely dissolved particles of the strengthening phases.

4. Conclusion

The frictional treatment of the PG-10N-01 high-strength (990 HV 0.025) NiCrBSi laser coating with a sliding hemispherical indenter made of dense cubic boron nitride additionally strengthens the surface to 1165–1220 HV 0.025 and forms favorable residual compressive stresses. As the load on the indenter grows from 300 to 1000 N, the level of residual compressive stresses increases from –55 to –1140 MPa.

Frictional treatment under a minimum load of 300 N does not change the initial phase composition of the surface layer, where, along with the Ni-based γ -solid solution and the γ +Ni₃B eutectics, there are the strengthening Cr₇C₃ and CrB phases. Only a partial strain-induced dissolution of borides and carbides seems to occur. The increase of the load on the indenter during frictional treatment to 500–700 N results in the intensive strain-induced dissolution of borides Ni₃B and carbides Cr₇C₃. This increases the lattice parameter of the Ni-based γ -solid solution and activates the solid-solution strengthening mechanism due to the enrichment of the solid solution with carbon, chromium and boron.

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